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Mobility risk: using ambulance operations data to analyze the spatial and social dimensions of health disadvantage

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ABSTRACT

The risk of death and disability for people after being struck by a car is unevenly distributed geographically and socially. This paper uses Emergency Medical Services records in Boston, Massachusetts, to analyze the characteristics of the locations where vehicles struck pedestrians and cyclists – and the characteristics of the neighborhoods where those individuals live. An individual's risk of encountering this sort of traffic risk, which we term *mobility risk*, is disproportionately higher among residents of neighborhoods with large shares of Black and Latino residents because of their disproportionate exposure to crashes both within and also outside of their home neighborhoods. Overall, residents of predominantly Black and Latino neighborhoods are about four times more likely than residents of predominantly white neighborhoods to be struck as a pedestrian; this disparity in crash exposure is almost 1.5 times larger than one would expect based on crash location alone. For residents of largely Black and Latino neighborhoods, being struck by a car is a common yet consequential phenomenon that reproduces health inequity.

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Health disadvantage; injury; urban sociology; spatial inequality

Introduction

Social scientists, epidemiologists, and clinicians focused on health equity have generated an extensive body of evidence regarding social, political, and environmental determinants of health (Krieger *et al.* 2003, Gordon-Larsen *et al.* 2006, White *et al.* 2012). In part because publicly available data are commonly collected based on residential location, much of the existing research focuses on the relationship between home neighborhood characteristics and exposure to place-based health risks, such as toxic industrial releases, or benefits, such as access to fresh food (e.g. Hipp and Lakon 2010, Hilmers *et al.* 2012). The uneven distribution of resources and of risks by residential neighborhood shapes stark inequalities in health, well-being, and socioeconomic mobility, through what are often called 'neighborhood effects' (e.g., Sharkey 2013, Sampson 2012, Sharkey and Faber 2014, Galster 2019). Some research also looks at the uneven distribution of occupational hazards, such as risk of injury, at different types of workplaces (e.g. Eakin 1992, Krieger 2010, Seabury *et al.* 2017, Flynn *et al.* 2021).

Locational risks and benefits – both in peoples' home neighborhood and at work, stores, and schools – is often starkly different by race and ethnicity. Yet, relatively few studies have connected characteristics of places of residence to risks encountered elsewhere. This is a significant gap, given that many people spend a large share of their time outside their home neighborhoods – and travelling to and from neighborhoods. In this paper, we evaluate the racially differentiated exposure to a major cause of health risk for people living in Boston – injuries and fatalities experienced by pedestrians and cyclists – by examining the features of residential *and* crash locations.

We know comparatively little about the health risks that exist for people beyond their home neighborhoods. People may be exposed to risk far from their home when they work, shop, learn, worship, and commute to and from these activities. Fully evaluating health risk requires linking phenomena that occur within a resident's own neighborhood with phenomena that residents experience elsewhere. If health risks in home neighborhoods are a high-priority area of policy intervention, the risk of exposure to injury outside of peoples' neighborhoods are also worthy of study.

We studied exposure to traffic injury, as a way of understanding the pathways between local health disadvantage and geographically-distant risk. Each year more Americans are injured from being struck by a car while walking and cycling than from house fires and natural disasters (CDC 2019). Recent analyses of coarse national data suggest troubling racial disparities in traffic crash risk that require additional fine-grained investigation (Chalfin and Massenkoff 2022, Leonhardt 2022).

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This article defines *mobility risk* as the possibility of being struck while walking or biking. Researchers have identified some aspects of how the built environment and street design shape crash incidence (e.g. Ewing *et al.* 2003, Graham and Glaister 2003, Loukaitou-Sideris *et al.* 2007, Eric and Rae 2009, Morency *et al.* 2012, Mansfield *et al.* 2018, Yu *et al.* 2018), tested the effectiveness of street design interventions (Campos-Outcalt *et al.* 2003, Noland *et al.* 2013, Richmond *et al.* 2014, Bella and Silvestri 2015, Chong *et al.* 2018, Kang 2019, Hamann *et al.* 2020), and assembled predictors of clinical outcomes (Maybury *et al.* 2010, Pour *et al.* 2017, Noland and Luz Laham 2018, Batouli *et al.* 2020), but we know comparatively little about how people living in different neighborhoods experience pedestrian and cyclist safety both within their home neighborhoods and elsewhere – and how their exposure to risk varies by the socio-economic characteristics of those neighborhoods. As Levy *et al.* (2020, p. 926) note in describing the concept of triple neighborhood disadvantage, 'the vitality of any given neighborhood is a function of the conditions in neighborhoods its residents visit and are visited by, and not only its residential (or nearby) socioeconomic conditions'.

To explore this combination of risks for people living in Boston – while overcoming the data challenges previous studies have had capturing risks near and far from home – we analyze unique 9-1-1 ambulance response records for pedestrians and cyclists struck by cars in the city from 2016 to 2021. This is an approach that readily extends to other cities. We investigate four research questions. First, at what frequency are pedestrians and cyclists struck by cars? Second, where do these incidents occur? Third, what are the characteristics of the home neighborhoods of those pedestrians and cyclists who are struck? Fourth, what characteristics of victims' home neighborhoods are associated with a higher likelihood of being struck – especially being struck far from home?

We find that in the average year citywide, 622 of Boston's approximately 650,000 residents are struck by cars as pedestrians or cyclists; this is equivalent to a member of roughly one in every 440 households in the city. Communities of color disproportionally experience roadway crashes – which can result in minor or major injury and even death – in two ways. First, we observe that crashes happen more in communities of color. Pedestrians and cyclists struck by cars with much greater frequency within the fifth of neighborhoods with the highest share of residents of color (those that are 97% non-white on average) than in the fifth of neighborhoods with the highest share of non-Hispanic white residents (88% white on average). Second, we find that people residing in communities of color are struck at high rates both near and far from their homes. While people who live in neighborhoods that are predominantly non-white account for about nine in ten victims struck in areas with similar racial composition, they *also* account for five in ten victims in neighborhoods where residents are predominantly white, and are more likely to be struck by a car in neighborhoods far from their homes. Poverty is correlated with race in Boston, as in other parts of the country; our findings on race generally hold for poverty.

Overall, we find that the disparity by home neighborhood racial composition in the incidence of pedestrians and cyclists struck by vehicles is almost 1.5 times larger than when just accounting for the neighborhood where the crash occurred. Though limitations in data about individual crashes do not allow us to measure differences in exposure for people of different races or ethnicities, we can show with Census data on neighborhoods that the mobility risk experienced by residents of largely non-white communities is a product both of experience within home neighborhoods and also what occurs when traveling.

Nationally, transport departments, including Boston's, use ambulance-system data on crashes to improve infrastructure. However, those records usually do not indicate where people involved in crashes are from, within the city or otherwise. This has historically complicated the interpretation of a result like observing high crash incidences in some neighborhoods with higher percentages of white residents. This is one policy reason behind us preliminarily untangling where people crash from where people involved in crashes are from.

Evidence on traffic crashes and race

Roadway crashes in the United States claim the lives of roughly 8,000 pedestrians and 1,000 cyclists per year. Pedestrian and cyclist deaths in the United States are rising (Retting 2018). In contrast, some European countries have successfully cut fatalities since the 1990s (Buehler and Pucher 2021, Freemark and Jenkins 2022). Beyond fatalities, the Centers for Disease Control and Prevention register 480,000 annual emergency department visits from pedestrians and cyclists treated for crash injuries (CDC 2019).

Nationwide, there are entrenched racial disparities in fatal crash incidence (unfortunately, there are no national data for non-fatal incidents). After adjusting for population size and incident type, there are between 1.2 and 2 times more Black than white pedestrians and cyclists who experience fatal crashes; Latinos experience similar but less severe disproportionate exposure (CDC 2019). This disparity holds after controlling for degree of traffic exposure and socioeconomics (CDC 2013). One explanation for these outcomes is increasing distances traveled by Black residents, an issue we highlight as well (Chalfin

and Massenkoff 2022). As reflected in hospital data, the morbidity from these crashes is higher for Black and Latino as compared to white pedestrians (Maybury *et al.* 2010, Hamann *et al.* 2020).

Observational studies show the built environment shapes crash risk

Crash injuries increase in the context of faster traffic flows, less dense neighborhoods, and large vehicles, suggesting that public health officials should monitor such features during interventions (Graham and Glaister 2003, Batouli *et al.* 2020, Malin *et al.* 2020). Many of these more dangerous features are more common in communities with a higher share of non-white residents (Morency *et al.* 2012).

Street design influences crash rates. Severe crashes occur more frequently when drivers are moving faster than 35 miles per hour (McMillan and Cooper 2019, Malin *et al.* 2020) or well above the speed limit (Goel 2021). Visibility also matters; severe crashes occur more after dark (Chong *et al.* 2018, Retting 2018) – despite more crashes occurring during the day (Batouli *et al.* 2020) – and when the road layout blocks drivers' views (Loukaitou-Sideris *et al.* 2007). Mobile phone prevalence in an area is also correlated with higher crash rates (Loeb and Clarke 2009). Roadway design explains a substantial portion of the excess traffic injuries occurring in neighborhoods where residents have low incomes, as they are more likely to have inadequately maintained, poorly designed streets (Morency *et al.* 2012).

Neighborhood land uses are also associated with crash rates. Pedestrian fatalities are higher in rural and suburban communities that have considerable separation between residential, retail, and other commercial land uses (Ewing *et al.* 2003, Eric and Rae 2009, Malin *et al.* 2020). Neighborhoods with higher population densities are safer (Graham and Glaister 2003), potentially because pedestrian crashes occur more frequently on roadways with more traffic, more lanes, and fewer crosswalks, which are more common in sprawling communities (Mansfield *et al.* 2018).

Finally, road vehicles and their characteristics, often related to transport and land-use decisions, impact crash outcomes. Victims are more likely to die when struck by buses and trucks (Chong *et al.* 2018), the latter of which serve warehouses that are more common in predominately lower-income and non-white communities (Yuan 2021). Vehicle mass and particularly frontal geometry (higher bumpers and hoods and more blunt frontal profiles associated with higher risks of head injury) are associated with higher likelihood of pedestrian fatalities (Lefler and Gabler 2004, Batouli *et al.* 2020, The Economist 2024). Sport utility vehicles, light trucks, and trucks have become more common over the past two decades.

Experimental evidence indicates race shapes crash risk

Though roadway safety and the built environment can explain some of the variations in traffic risk exposure, these dimensions cannot explain the full variation in exposure to roadway crashes. Experimental evidence about car drivers indicates pedestrian and cycling safety is also influenced by discrimination (LaVeist 2005), though studies cannot make claims about drivers' implicit versus explicit biases. Controlled experiments involving pedestrians attempting to cross streets at crosswalks show that drivers are twice as likely to stop for white male pedestrians as Black men, increasing waiting time for Black walkers. Drivers – themselves men or women, Black or white – are also more likely to stop *closer* to Black pedestrians, potentially putting them in more danger (Goddard *et al.* 2015, Coughenour *et al.* 2017, Kahn 2017). Moreover, drivers are more likely to commit hit-and-run crashes against Black pedestrians than white pedestrians (Kurmangaliyeva and Sostero 2021), which could influence the speed with which victims receive aid. Altogether, researchers have demonstrated that race factors into traffic crash risk.

Initial analyses show neighborhood effects impact crash risk

There is ample evidence demonstrating relationships between neighborhood characteristics, such as socioeconomic status, and health outcomes (Arcaya *et al.* 2016). These associations may result from long-term stressors, poor environmental conditions, and limited resources (Ellen *et al.* 2001). While moving from a high- to low-poverty neighborhood may improve mental health, there is less evidence for residential locations' impacts on physical health (Leventhal and Brooks-Gunn 2003, Kling *et al.* 2007) – health differences are likely a product of the combination of race, long-term exposure to poverty, and poor governmental services, among other influencers (Schulz *et al.* 2000).

As noted, previous research has largely examined crash occurrence based on the neighborhoods where they occur. Communities with a higher share of low-income residents and residents of color face higher levels of pedestrians struck by vehicles (Noland *et al.* 2013, Yu *et al.* 2018). This could be a satisfactory picture of injury if people were only involved in crashes near where they lived – but people move about the metropolitan area as part of their day-to-day lives.

There is less fine-grained evidence on crash patterns based on the characteristics of the people struck in part because of the barrier to securing data that link victim, crash location, and home location. The few

studies that begin to overcome this hurdle are revealing. Notably, the socioeconomics of a crash victim's residential neighborhood predict clinical outcomes (Pour *et al.* 2017). Hit-and-run accidents with Black victims are more likely when crashes occur in neighborhoods with a higher share of white residents (Kurmangaliyeva and Sostero 2021). More insight is needed, however, into the full extent of crash risk over peoples' daily lives and across a city. Daily life is rarely limited to staying only in one's home neighborhood (Silm and Ahas 2014).

Data and methods

To understand associations between the characteristics of the environments where people are hit when walking or cycling, along with the characteristics of the neighborhoods in which they reside, we use patient, street, and Census-level data in a case-study city. This is an approach that could be readily extended to other cities. Identifying these connections enables us to conceptualize exposure to traffic crash risk not only as a key component of public health but also one that is influenced by the characteristics of both crash sites and victims' residential neighborhood.

Patient data for victim and crash information

Finely segmented ambulance demand is one way of revealing social and health patterns over time and neighborhoods (Brennan *et al.* 2022, 2024). We use a dataset encompassing the universe of all Boston residents who were pedestrians or cyclists when struck by a vehicle in the city between January 2016 and June 2021, and for which there was a Boston EMS response. Emergency Medical Service (EMS) crews complete care reports to capture each victim's (now patient's) gender, age, and residential address. The public safety computer aided dispatch system automatically generates information on the date, time, and location of each crash. Information on patient race or ethnicity is not collected during the 9-1-1 response. The department's information management team manually reviews all potential cyclist and pedestrian incidents, ultimately producing a comprehensive, vetted dataset. Boston EMS specifically tracks pedestrian and cyclist crashes because these are preventable incidents and such data could be used to inform roadway infrastructure improvements. Nationwide, nationwide, pedestrians and cyclists are 23 and 12 times, respectively, more likely to experience fatal injuries than car occupants in crashes, adjusting for miles traveled (Pucher and Dijkstra 2003). We compare each victim's home neighborhood to crash locations, defining those that are '*close to home*' as less than three average Census block group widths between home and crash (block groups average about one-quarter of a mile in width). Geographically distant, or '*far-off*', crashes are those further away than three block group widths.

During the study period, there were 3,435 pedestrians and cyclists who lived in Boston who were struck by vehicles at crash sites in Boston (we do not include data on crashes in Boston involving victims who lived outside of Boston, or crashes outside of Boston involving victims who lived in Boston). From 2016 to 2019, there were an average of 60 such crash victims per month; this declined to 32 per month in the study months that coincided with the COVID-19 pandemic, likely because fewer people were on the streets during that period. Despite the decline in overall pedestrians and cyclists struck, crashes were distributed around the city similarly during the two periods (Appendix Table A1).

We drop records for just under 2.5% of patients who were involved in a crash in Census block groups such as industrial parks where there is no Census information on resident demographics. We do not include motorized bike crashes. Our data is for pedestrians and cyclists who are struck by cars. As a check, we also attempt to flag two subpopulations – people experiencing homelessness, who give no home address (nationally 0.2% of the population), as well as 4-year college students, who give their parents' addresses (nationally 2% of the population). This dataset also does not include crashes for which EMS was never called, likely omitting ones with no emergent medical need. We suspect that few significant crashes were omitted overall because it is common for bystanders, victims, and drivers to call 9-1-1 regardless of whether medical needs are emergent.

City data for crash site features

To further gain insight into the characteristics of the built environment of the locations where people were involved in crashes, we join patient records by crash location with three spatial products maintained by the City of Boston: the location of roads and their associated posted speed limits; crosswalks; and bike lanes.[1]

Census data for neighborhoods characteristics

To draw inferences about neighborhood characteristics, we use data at the Census block-group level.[2] We source data from the five-year U.S. Census American Community Survey, 2016-20. We link all residential and crash locations with their respective block groups.[3] There are 550 block groups in Boston with resident populations; these average 1,240 residents.

For each block group, we collect its population; share of residents by race and ethnicity; access to vehicles by household; commute times and modes

Table 1. Characteristics of Boston block groups, by racial or ethnic majority.

	Block groups with a majority of residents who are…				
	White	Black	Asian	Hispanic	*No majority*
Number of residents in relevant block groups	326,225	128,725	10,835	50,774	174,621
Mean share of overall city population of that race or ethnicity living in these block groups	76.7%	58.6%	10.9%	24.2%	–
Mean jobs per resident	1.83	0.94	1.78	0.15	1.26
Mean share of residents commuting 30 min+	48.8%	62.0%	56.0%	63.3%	54.8%
Mean share of residents commuting 45 min+	20.5%	31.1%	20.6%	26.1%	23.1%
Mean share of workers commuting by transit, walk, or bike	49.0%	40.1%	58.2%	50.2%	48.1%
Mean share of households with no car	30.2%	33.9%	52.8%	37.5%	36.4%
Mean share of residents in poverty	12.5%	22.4%	41.0%	27.2%	24.1%

Sources: American Community Survey, 2016–20 data; Census Longitudinal Employment-Household Dynamics 2020 data.

for workers; share of population by age; and educational attainment and poverty levels. We collect data about resident car access, since that helps explain where automobile reliance is more common. We also collect data from U.S. Census Longitudinal Employment-Household Dynamics to establish the number of jobs located in each block group in 2019.[4]

We choose block groups as our unit of analysis because they are the smallest geographic area with available data on economic, demographic, and social factors shaping crash risk.[5] The EMS records do not include information on patient race; accordingly, we use Census data on neighborhood demographics as a proxy for patient demographics.

Nonetheless, neighborhood data are informative in illustrating the extent of segregation and demographic difference. In Table 1, we compare demographic attributes for block groups in Boston based on whether they have a majority of residents of one race or ethnicity – or no racial or ethnic majority. Though the population of Boston was 45% non-Hispanic white ('white' from here on) in the 2016–20 data, 77% of the city's white residents lived in neighborhoods that were more than 50% white. Similarly, 22% of the city's residents identified as non-Hispanic Black ('Black' from here on), but 59% of the city's Black residents lived in neighborhoods that were more than 50% Black. Several neighborhood attributes are relevant to travel patterns. Majority Black and Latino neighborhoods, for example, have substantially fewer jobs per capita than majority white or Asian neighborhoods; workers who live in majority Black and Latino neighborhoods are also more likely to have commutes longer than 45 min, and, compared to white-majority neighborhoods, households therein are less likely to own a car. Finally, Table 1 shows the links between neighborhood racial composition and poverty rates, showing that majority-white neighborhoods have substantially lower poverty rates than other neighborhood types.

Limitations

Our study is limited in that it does not directly examine the race of crash victims but rather uses neighborhood demographic data to make connections between average neighborhood conditions and crash exposure. Our study also focuses on crashes for people who reside in Boston to be able to appropriately compare in absolute terms crash frequencies in home versus incident neighborhoods. The study is of course descriptive, and follow-on causal work might reveal the mechanisms that lead crash rates to occur unevenly between neighborhoods. Qualitative work is one approach to further analyze causality in this process and the actual experiences of pedestrians and cyclists who are struck by vehicles. Additional work focused on other cities may also be a starting point to affirm similarities and flag differences between contexts.

Results

Table 2 summarizes data about the pedestrians and cyclists struck by vehicles; the streets and neighborhoods where crashes occur; and the neighborhoods where victims live. Cyclists who are hit by cars, unlike pedestrians, are more likely to be men than women; they are also likely to be young. Neighborhood racial or ethnic composition differs substantially between where victims are involved in a crash and where they live, especially for pedestrian crashes. Pedestrians tend to be struck in neighborhoods with populations that are 3.6% points whiter than where they live (the average crash involving a pedestrian occurred in a neighborhood whose residents were 34.7% white, even though that pedestrian themself lived in a neighborhood that was 31.1% white on average). Moreover, the average crash victim lives in a neighborhood with more residents of color than the average city neighborhood. Relative to pedestrian crashes, cyclists involved in crashes were almost 10 percentage points more likely to reside in whiter neighborhoods and the neighborhoods where their crashes occurred

Table 2. Summarizing victim, crash site, and neighborhood characteristics.

	Pedestrian Crashes		Bike Crashes	
Total crash count	2,223		1,200	
Victim mean characteristics				
Age	40.1		35.0	
Gender (% male)	48.9		75.8	
Distance from home (miles)	1.1		1.3	
Crash site mean characteristics				
Speed Limit	24.1		23.8	
% near (within 30m) cross walk	75.6		71.5	
% near (within 30m) bike lane	44.4		49.7	
Neighborhood mean characteristics				
	Pedestrian home neighborhood	*Crash site neighborhood*	*Cyclist home neighborhood*	*Crash site neighborhood*
Crashes	7.5	10.8	4.4	5.7
Pop. (in 1000s)	1.4	1.4	1.4	1.4
Crashes per pop. (pop. in 1000s)	5.9	10.1	3.5	4.9
Jobs (in 100s)	14.8	27.6	13.2	28.0
Crashes per job (jobs in 100s)	12.1	7.7	5.8	3.5
% White pop.	31.1	34.7	42	43.3
% Black pop.	32.8	30.2	24.6	23.3
% Hispanic pop.	23.9	22.0	20.3	19.3
% Asian pop.	8.6	9.6	9.2	10.4
% Commuters – 5am-7am	21.3	20.0	19	18.2
% Commuters – 4pm-12pm	6.4	6.1	5.4	6.0
% Households - no car access	36.2	38.8	32.5	38.5
% Commuting by transit	35.8	35.6	35.3	35.2
% Commuting by walking	12.5	14.8	12.4	16.9
% Commuting by biking	1.9	1.9	2.8	2.2
% Commuting by car	45.5	43.1	44.7	40.7
% Under-18 pop.	27.4	25.2	24.1	22.0
% Over-60 pop.	31.6	31.1	29.9	29.9
% Pop. with BA or higher	38.0	41.0	47.3	48.2
% Households in poverty	23.5	23.8	20.5	22.0

The first panel (vertically) reports the count of crashes. The second panel reports the average victim characteristics of pedestrian and cyclists involved in crashes. The third panel reports average crash site characteristics for both types of crashes. The bottom panel reports average neighborhood (block group) characteristics of both victim home neighborhoods and the neighborhood where crashes occurred. For interpretation: The average pedestrian involved in a crash lived in a neighborhood with an average resident population that was 31.1% white, but the crash itself occurred in a neighborhood with an average resident population that was 34.7% white.

Sources: Victim characteristics sourced from Boston EMS data. Crash site data compiled from City of Boston information. Neighborhood averaged characteristics sourced from American Community Survey, 2016–20 data.

had higher white resident populations, too. These outcomes may reflect differences in the demographics of people who walk or bike overall, which is not captured in the data available.

The neighborhoods where pedestrians and cyclists are involved in crashes

We examine where victims are involved in crashes as an initial assessment of place-based risk and the characteristics of the neighborhoods where crashes happen. To provide an initial descriptive picture, we divide the 550 block groups in Boston into five quintiles, with the first quintile holding the 110 neighborhoods with the lowest percentage of white residents and the fifth quintile holding the 110 neighborhoods with the highest percentage of white residents. In Table 3, we describe the average demographics of each of these quintiles and what information we know about the victims of *crashes that occurred within each of these quintiles*. The quintiles have similar populations, but the first quintile (with the smallest share of white residents) has a small number of jobs, suggesting that people who live in those areas must travel longer distances to employment.

Overall, there are many more crashes in neighborhoods with a smaller white population share; there are 2.7 times as many pedestrians struck by vehicles in the least white compared to the whitest neighborhoods and adjusting for population and employment density of the crash neighborhood reinforces this trend (e.g. there are 4.7 pedestrian crashes per 1,000 residents in the least white neighborhoods, compared to 1.9 per 1,000 residents in the most white). This difference is even starker when accounting for both population and jobs. This finding aligns with previous research that explores the neighborhood composition of where crashes happen (Noland *et al.* 2013, Yu *et al.* 2018). The association between counts of cyclists struck by vehicles and neighborhood demographics is less clear. Cyclists struck are most likely to occur in neighborhoods with a middle level of white resident shares (those with resident populations that are about 49% white), suggesting no linear association, although there is a relationship once accounting for jobs as well.

Cyclists are struck further from home than pedestrians. Table 3 shows that the average crash involving a pedestrian occurs about one mile from that pedestrian's home, though there is only a 0.2-mile difference between the least white and whitest

Table 3. Descriptive statistics of neighborhoods *by* crash *location*, divided into quintiles by crash-neighborhood percentage white residents.

Neighborhood quintile by percentage of residents who are white	Neighborhoods where pedestrians are involved in crashes					Neighborhoods where cyclists are involved in crashes				
	Least white			Most white		Least white			Most white	
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Mean demographics by crash neighborhood quintile										
Pop. (in 1000s)	135	149	149	125	125	135	149	149	125	125
Jobs (in 100s)	160	1047	1121	3225	1187	160	1047	1121	3225	1187
% White pop.	3.1	21.1	49.2	68.3	87.9	3.1	21.1	49.2	68.3	87.9
% Black pop.	62.7	30.1	12.7	5.6	1.8	62.7	30.1	12.7	5.6	1.8
% Hispanic pop.	27.6	32.7	18.8	9.8	5.0	27.6	32.7	18.8	9.8	5.0
% Asian pop.	3.2	12.8	15.0	12.1	3.5	3.2	12.8	15.0	12.1	3.5
% Households with no car access	36.4	35.5	36.4	32.3	24.0	36.4	35.5	36.4	32.3	24.0
Crash data by neighborhood quintile										
Total crashes	629	612	396	337	233	223	254	262	258	155
Number of neighborhoods (of 110) with at least one crash	105	89	90	77	68	91	78	74	74	61
Crashes per pop. (in 1000s)	4.7	4.1	2.7	2.7	1.9	1.7	1.7	1.8	2.1	1.2
Crashes per job (in 100s)	3.9	0.6	0.4	0.1	0.2	1.4	0.2	0.2	0.1	0.1
Crashes per pop. and job (in 1000s)	4.2	2.4	1.5	0.8	1.0	1.5	1.0	1.0	0.6	0.6
Mean victim characteristics by neighborhood quintile										
Age	37	42	38.9	41.3	42.7	34.4	34.7	34.3	36.3	34.5
Gender (% male)	49.6	49.3	51.3	48.7	46.4	84.8	79.9	72.1	70.2	72.3
Distance from home (miles)	0.9	1.1	1.1	1.4	1.1	0.9	1.2	1.3	1.5	1.5

The top two panels report quintile characteristics in terms of demographics and crash data. The bottom panel reports the average victim characteristics in each quintile. The left panel is for pedestrian crashes and the right for bike crashes. About 2.25% percent of records lack home or crash residential information and thus are not included.

Sources: Victim characteristics sourced from Boston EMS data. Neighborhood average characteristics sourced from American Community Survey, 2016–20 data and U.S. Census Longitudinal Employment-Household Dynamics 2019 data.

neighborhoods. Cyclists struck, on the other hand, see a 0.6 mile spread across the quintiles. These trends are illustrated visually in Appendix Figure A1. The pedestrians and cyclists struck in neighborhoods with higher shares of residents of color are struck slightly closer to home, as compared to those struck in neighborhoods that are whiter. In other words, people struck in whiter neighborhoods, and especially bikers struck in whiter neighborhoods, have traveled further.

Table 4. Descriptive statistics of neighborhood by victim home location, divided into quintiles by home-neighborhood percentage white residents.

Neighborhood quintile by percentage of residents who are white	Victim home location of pedestrians involved in crashes					Victim home location of cyclists involved in crashes				
	Least white			Most white		Least white			Most white	
	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
Mean demographics by home neighborhood quintile										
Pop. (in 1000s)	135	149	149	125	125	135	149	149	125	125
Jobs (in 100s)	160	1047	1121	3225	1187	160	1047	1121	3225	1187
% White pop.	3.1	21.1	49.2	68.3	87.9	3.1	21.1	49.2	68.3	87.9
% Black pop.	62.7	30.1	12.7	5.6	1.8	62.7	30.1	12.7	5.6	1.8
% Hispanic pop.	27.6	32.7	18.8	9.8	5.0	27.6	32.7	18.8	9.8	5.0
% Asian pop.	3.2	12.8	15	12.1	3.5	3.2	12.8	15.0	12.1	3.5
% Households with no car access	36.4	35.5	36.4	32.3	24.0	36.4	35.5	36.4	32.3	24.0
Crash data for residents living in these neighborhood quintiles										
Total crashes	791	558	377	302	195	275	232	297	215	181
Number of neighborhoods (of 110) with at least one crash	109	107	98	89	84	92	88	91	83	75
Crashes per pop. (in 1000s)	5.9	3.7	2.5	2.4	1.6	2.0	1.6	2.0	1.7	1.4
Crashes per job (in 100s)	4.9	0.5	0.3	0.1	0.2	1.7	0.2	0.3	0.1	0.2
Crashes per pop. and job (in 1000s)	5.2	2.2	1.4	0.7	0.8	1.8	0.9	1.1	0.5	0.7
% crashes in whiter-than-median block group	13.2	22.6	50.5	70.4	80.6	16.2	31.7	58.4	67.8	77.4
% crashes in far-off block group (> 0.6 mi.)	46.3	45.8	44.8	45.7	35.4	53.5	60.8	64.5	65	62.2
% crashes in whiter + close block group	2.2	8.1.0	30.5	43.9	58.6	2.2	5.8	19.9	29.3	35.7
% crashes in less white + far-off block group	35.0	31.0	24.1	18.4	12.0	39.0	33.5	24.9	24.9	17.9
% crashes in whiter + far-off block group	11.0	14.4	20.0	26.5	22.0	14.0	25.9	38.4	38.5	41.7
Mean victim characteristics by neighborhood quintile										
Age	37.3	40.5	40.2	43.6	44.3	32.8	33.7	33.2	38.7	38.4
Gender (% male)	47.5	50.2	49.9	49.7	47.7	86.2	83.2	70.7	69.8	65.7
Distance from home (miles)	1.0	1.2	1.1	1	0.9	1.0	1.3	1.4	1.4	1.4

The top two panels report quintile characteristics in terms of demographics and crash data. The bottom panel reports the average victim characteristics in each quintile. The left panel is for pedestrian crashes and the right for bike crashes. About 2.25% percent of records lack home or crash residential information.

The neighborhoods where pedestrians and cyclists involved in crashes live

We next examine the *neighborhoods in which crash victims live*. In Table 4, we assign the 550 block groups to the same five quintiles according to percentage of residents who are white. We then assign each crash victim to the quintile in which they live rather than the quintile in which they were hit (as we did above). We count crashes in three ways: first, all of the instances in which pedestrians and cyclists are struck by cars; second, those crashes that occur in neighborhoods geographically distant from the victim's home neighborhood, as defined in Section 'Data and methods'; and, third, those crashes that occur in what are relatively white neighborhoods, i.e. those neighborhoods with a greater share of residents who are white than the citywide median (49.8%).

Examining traffic crash risk by victim *home* neighborhood instead of by the neighborhood where the *crash* occurred paints a picture of mobility risk that even more disparately impacts people who reside in neighborhoods largely populated by people of color and is especially severe for pedestrians struck by vehicles. Table 4 shows there are 4.1 times as many pedestrians struck involving residents of the neighborhoods with the largest share of residents of color compared to those with the highest white population shares (e.g. there were 5.9 pedestrians struck per 1,000 residents from the neighborhoods with an average of 3.1% white residents, versus 1.6 per 1,000 from those with an average of 87.9% white residents). In other words, people living in neighborhoods where almost all residents are people of color are almost twice as likely to be struck by a car as residents of neighborhoods that are overwhelmingly white, in part because they are more likely to be struck a car not only in their own neighborhood but also in neighborhoods distant from their home. Comparing this disparity with the fact that 2.7 times as many pedestrians are struck by vehicles in the neighborhoods with the largest share of residents of color compared to the whitest neighborhoods reveals a 1.5 times larger spread between neighborhoods in crash burden than was previously understood by research that focuses on just where crashes occur. Again, this pattern of disparity is even larger when the ratio is adjusted for job counts. Overall, similar, though less extreme, differences are apparent for cyclists struck by vehicles. Figure 1 compares the home addresses of victims with the locations of pedestrian and cycling crashes.

Table 4 shows that many of the pedestrians and cyclists struck by cars are struck far from home, but that this risk is not evenly distributed. Nearly half of the struck pedestrians who live in the 80% of neighborhoods with the largest share of residents of color are struck far from where they live. Just about a third of victims who live in the 20% of neighborhoods with the highest share of white residents, however, are involved in a crash far from home. In absolute terms, there is consistently a ten-percentage point difference in the share of victims involved in a crash far from home between the least white (first four) quintiles and the whitest quintile: this translates to an excess of 202 far from-home crash victims from the first four quintiles, which for context is more than the *total* number of pedestrian crash victims who live in top, whitest quintile (195).

These experiences of people who live in neighborhoods with large shares of residents of color and who are struck by vehicles as pedestrians and cyclists not only often occur far from home but also occur far from home in neighborhoods whose residents are more likely to be white, as Table 4 indicates. Of the pedestrians struck by cars, 13.2% of the victims who live in the neighborhoods with the largest share of residents of color, making up the first quintile, are struck by

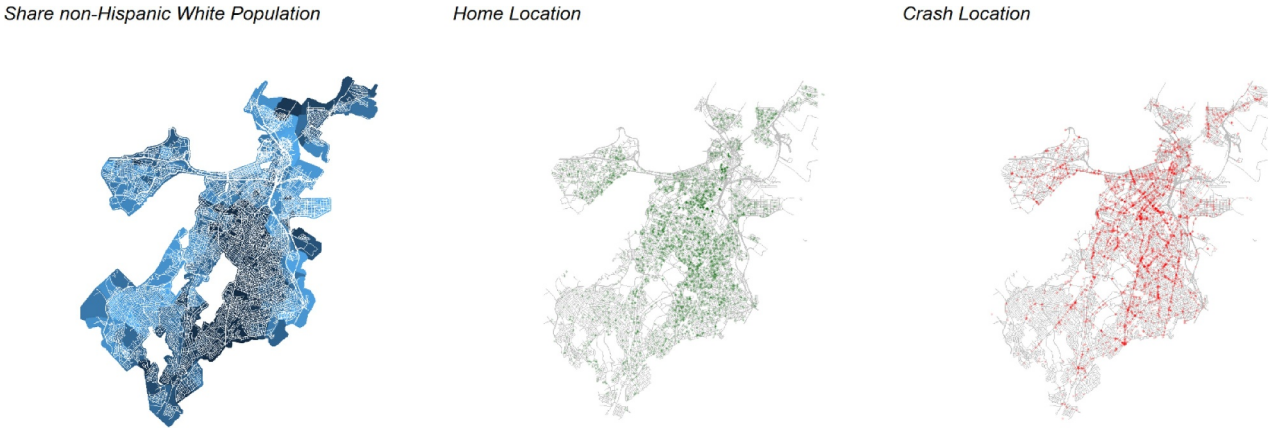

Figure 1. Demographics, crash victim residence locations, and crash locations. Neighborhood race (pale blue is more white, dark blue is less white), victim home location, and victim crash location for the City of Boston, overlaid on city streets. *Sources*: Race/ethnicity data from U.S. Census American Community Survey, 2016–20. Victim location data from Boston EMS.

vehicles in areas with higher than the citywide median of share white residents. (The first quintile neighborhoods are 97% people of color and the citywide median is roughly 50%). In absolute terms, of the 791 pedestrians struck by cars from those largely non-white neighborhoods, this means 104 victims were struck in these areas where white residents predominate. Conversely, just 38 victims who live in the neighborhoods with the highest white population share, making up the top quintile where 88% of residents are white, were involved in crashes in areas with *less* than the citywide median white resident share. In short, 104 victims from the most non-white neighborhoods were struck in majority white areas, while just 38 victims from the whitest neighborhoods were struck in majority non-white areas.

Taken together, compared to victims from neighborhoods with a higher white population share, pedestrians living in neighborhoods with a large share of residents of color, in both relative and absolute terms, are more likely to be involved in crashes further from home and in neighborhoods that have higher white population shares. Appendix Figure A1 illustrates the relationship between home location and distance between home and crash. Note that these racial trends were not as pronounced for cyclists involved in crashes, but they persisted.

One trend visible in Table 4 is that both pedestrian and cyclist victims who live in neighborhoods with a higher share of white residents are older than those in neighborhoods with a smaller share of white residents. One explanation for this may be that the median person of color is slightly younger than the median white person in Boston (31.6 versus 32.8 years old in 2020). It may also be that younger people of color are more likely to walk as part of their commute than their white peers.

Visualizing the information in Table 4, Figure 2 represents where pedestrians and cyclists are struck by vehicles relative to where they live. Pedestrians living in neighborhoods where the majority of residents are people of color are disproportionately exposed *both* to crashes near where they live *and also* to crashes far away, including those where white residents predominate. These differences are all the more surprising because Black and Latino Boston residents walk or take transit to commute at a slightly lower rate than white residents; that said, the commuting distances of people of color are longer (especially given the few jobs in largely non-white neighborhoods), which may expose them to more time walking.[6] The trends in cyclists struck, however, do not display as clear of a linear relationship.

In Figure 3, we show the same data as in Figure 2, but in terms of proportions. These data show that crashes involving pedestrians living in largely white neighborhoods almost all occur in areas nearby, and in areas where a majority of residents are white. This is not the case for crashes involving pedestrians living in neighborhoods with large shares of residents of color.

Differing crash burdens among varying home neighborhood types

In addition to analyzing the neighborhood racial and ethnic demographics of victims' home neighborhoods, we also examine other neighborhood characteristics such as income and poverty level. In Table 5, we assign the 550 block groups and the crash victims associated with each block group based on the neighborhoods *where they live*, into quartiles according to different characteristics. The bottom quartile (least, Q1) represents the 138 block groups with the lowest share of that characteristic (e.g. smallest share in poverty), and

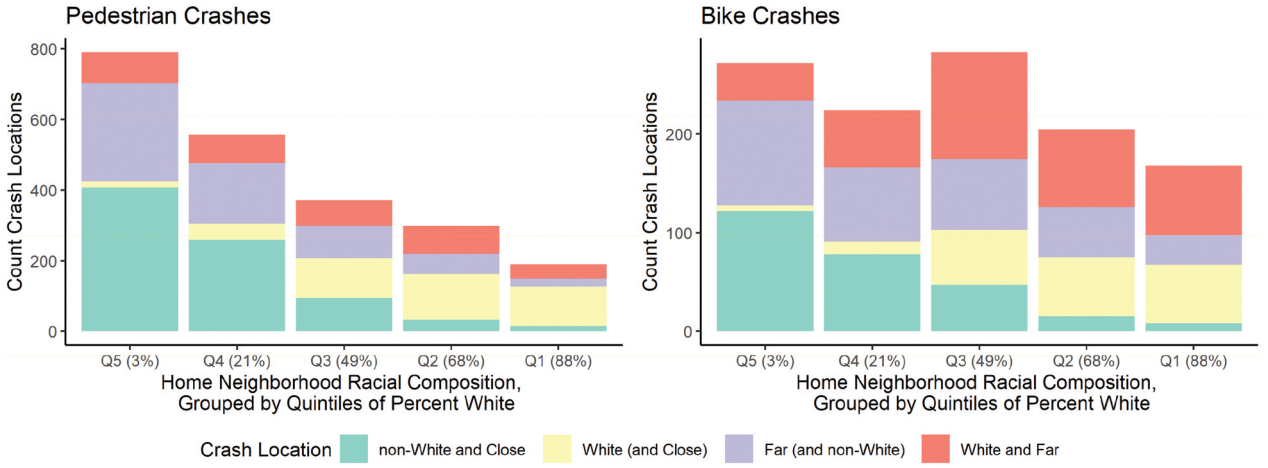

Figure 2. Crash locations, by victims' home neighborhood. The stacked bar height is the count of victims, with the coloring representing where the crash occurred relative to their homes and the crash location neighborhood's racial makeup. The x-axis is the share white residents for the victim's home neighborhood, sorted into quintiles of percent white. Close neighborhoods mean those within about two-thirds of a mile from victim's residence neighborhood; far neighborhoods are further away. Though Figure 2 is not adjusted per-capita, the populations of each of the quintiles is roughly similar, as the top panels of the preceding tables show. *Sources:* Race/ethnicity data from U.S. Census American Community Survey, 2016–20. Victim location data from Boston EMS

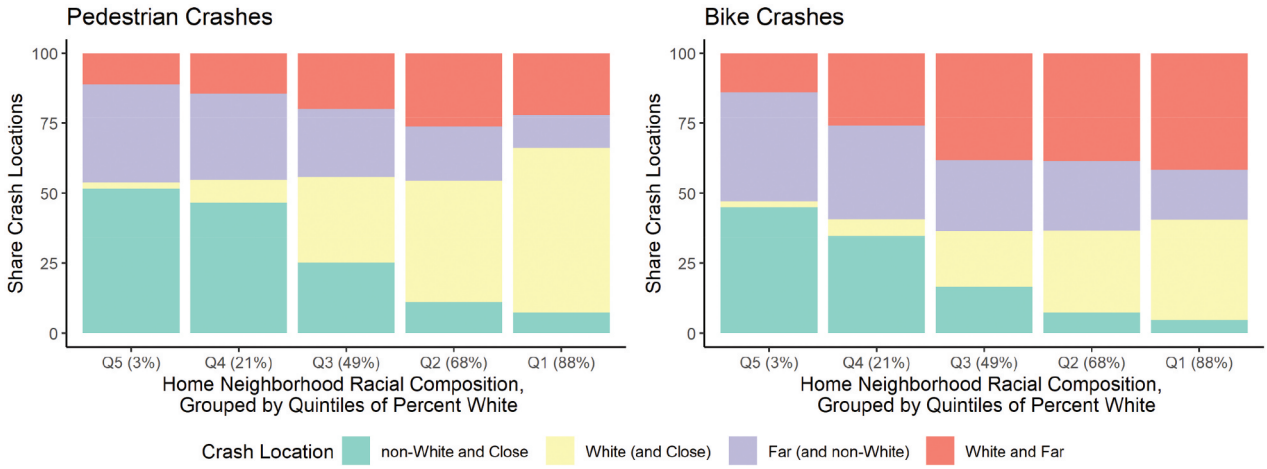

Figure 3. Crash locations, by victims' home neighborhood. The stacked bar height is the percentage of crash victims within that quintile. The x-axis is the share white residents for the victim's home neighborhood, sorted into quintiles of percent white. Close neighborhoods mean those within about two-thirds of a mile from victim's residence neighborhood; far neighborhoods are further away. *Sources:* Race/ethnicity data from U.S. Census American Community Survey, 2016–20. Victim location data from Boston EMS

the top quartile (most, Q4) represents the 138 block groups with the highest share (e.g. largest share in poverty).[7] We construct a ratio defined as the median number of pedestrians or cyclists struck per capita in Q4 relative to Q1. When the ratio is greater than one, Q4 had more pedestrians or cyclists struck per capita than Q1 (e.g. the ratio would be greater than one with more per-capita pedestrians struck in the neighborhoods with the highest poverty rate than in the neighborhoods with the lowest poverty rate). Table A2 presents crash frequency in this way by characteristics of the neighborhoods *where crashes occurred*.

Table 5 shows that across all characteristics, the biggest disparity in per-capita crashes between the lowest and highest quartiles exists when neighborhoods are grouped in terms of the share of Black residents, with four times as many pedestrians who live in the neighborhoods with the highest Black population shares struck per-capita far from home versus those who live in the neighborhoods with the lowest. Pedestrians who live in neighborhoods with the highest share of Black residents are also more often hit walking far away from home relative to those who live in neighborhoods with the lowest shares of Black residents. For cyclists, an especially large disparity in per-capita crashes exists when neighborhoods are grouped in terms of their share of residents with a bachelor's degree or higher. Cyclists from neighborhoods with the highest share of residents with a bachelor's degree are twice as likely to be hit while biking in neighborhoods with a high share of white residents (to be expected given the correlation between higher education levels in a neighborhood and a higher share of white residents). This likely reflects the fact that people with higher education are more likely to be white.

A mix of neighborhood assets, income, and job schedules also influences crash incidence. Less household car access in a victim's home neighborhood is significantly associated with a higher rate of crashes involving pedestrians (a) overall, and (b) in far-off, (c) whiter, and (d) far-off and whiter neighborhoods (perhaps unexpected, given that more people are likely walking). The share of households in poverty has a similar significant association with an increase in the likelihood of pedestrians being struck. Poverty, race, and access to vehicles are all correlated with each other in Boston, as in other parts of the country. Job schedules, finally, also influence crash incidence. Neighborhoods with high shares of early (5am-7am) and second-shift and third-shift (4pm-12am) commuters have a higher share of residents experiencing more far-off crashes, perhaps because residents' daily travel is more likely to involve longer walking trips in the dark.

The linear regression model estimates in Table 6 reinforce the insights from Table 5, helping to isolate which of the neighborhood characteristics are more definitively associated with crash incidence. We regress the per-capita counts of residents struck by vehicles, and of residents struck by vehicles in (a) predominantly white, (b) far-off, or in (c) white and far-off neighborhoods, against characteristics selected from Table 6 that encompass its racial, commuting, and income concerns without posing collinearity problems.[8]

As documented elsewhere, we find that neighborhoods with high Black and Latino population shares experience more resident pedestrians or cyclists struck by vehicles. Among pedestrians struck far from home,

Table 5. Comparison of top and bottom quartile of various characteristics of victims' home neighborhoods, by location and racial or ethnic composition of crash neighborhood.

	Quartiles		Pedestrian crashes, by crash location								Bike crashes, by crash location							
	Median of block groups in quartile		Ratio of median victims counts of block groups in Q4 relative to Q1								Ratio of median victims counts of block groups in Q4 relative to Q1							
Home neighborhood characteristics	Bottom quartile (Q1)	Top quartile (Q4)	All		Crash in white neighborhood (>median)		Crash in far neighborhood (> 0.6 mi.)		Crash in white & far neighborhood		All		Crash in white neighborhood (>median)		Crash in far neighborhood (> 0.6 mi.)		Crash in white & far neighborhood	
Pop. (in 1000s)	0.6	2.1	0.6		0.5		0.8		0.6		0.6		0.5		0.6		0.6	
Jobs (in 100s)	0.2	45.4	1.0		1.8	**	1.1		1.3		1.2		1.5		0.9		1.0	
% White pop.	4.8	85.6	0.3	***	1.7	**	0.2	***	0.5	*	0.7	**	2.5	***	0.8		1.8	*
% Black pop.	0.4	63.4	3.0	***	0.6	*	4.0	***	1.5		1.7	*	0.3	***	1.5		0.6	*
% Hispanic pop.	2.7	44.6	1.9	***	0.8		2.1	***	1.4	*	1.2		0.4	***	0.9		0.5	*
% Asian pop.	0.0	26.3	0.6	**	2.0	***	0.5	***	0.9		1.2		2.4	***	1.1		1.8	*
% Commuters – 5am-7am	6.8	36.2	1.2	*	0.8		1.3	*	0.9		0.8		0.4	***	0.9		0.5	*
% Commuters – 4pm-12pm	0.2	13.9	1.2	.	0.7	*	1.3	*	0.8		1.0		0.6	*	0.9		0.6	
% Households no car access	7.9	61.7	2.0	***	1.6	**	1.6	*	1.2		1.0		0.7		0.7	*	0.6	*
% Commuting by transit	15.4	53.9	1.7	***	1.1		1.6	*	1.3		1.7	*	1.2		1.6		1.5	
% Commuting by walking	0.1	41.6	0.9		2.0	***	0.9	**	1.0		1.0		1.3		0.7		0.7	
% Commuting by biking	0.0	6.8	0.6	**	1.2		0.6	***	0.7		1.1		1.7	*	1.2		1.7	
% Commuting by car	18.9	71.7	1.0		0.6	**	1.2		0.6		0.9		0.8		1.1		1.0	
% Under-18 pop.	4.4	45.2	2.0	***	0.6	***	2.6	***	1.2		1.1		0.3	***	1.0		0.5	*
% Over-60 pop.	12.2	51.4	1.5	.	0.7	**	1.8	.	0.9		1.0		0.8	*	0.9		0.8	
% Pop. with BA or higher	14.9	83.9	0.3	***	1.8	***	0.2	***	0.6	*	0.8		2.1	***	0.9		1.7	*
% Households in poverty	3.2	43	2.3	***	1.3		1.9	***	1.1		1.2		0.7	*	0.8		0.6	*
Distance traveled – ped.	0.2	2.5	1.3	*	0.7	*	8.5	***	5.3	***	-		-		-		-	
Distance traveled – bike	0.4	2.9	-		-		-		-		1.3	*	1.6	*	4.1	***	5.0	***

The leftmost panel reports the average among the block groups in the bottom quartile (Q1) and in the top quartile (Q4) for that characteristic. The second and third panels report the ratio of the average crash count per capita for Q4 to the average crash count per capita for Q1. The significance noted is the outcome of a Wilcox Test, which compares the distribution of crash counts for block groups in Q1 to the distribution of crash counts in Q4. The null hypothesis is there is no difference between the distributions. ***$p < 0.001$, **$p < 0.01$, * < 0.05.

Sources: Victim characteristics sourced from Boston EMS data. Neighborhood average characteristics sourced from American Community Survey, 2016–20 data and U.S. Census Longitudinal Employment-Household Dynamics 2019 data

residing in a neighborhood with a higher share of Black or Hispanic residents is associated with a higher likelihood of being struck as a pedestrian, even after adjusting for covariates. Neighborhoods with a high share of bike commuters and fewer early morning commuters face higher levels of cyclist crashes. Residing in a neighborhood with a higher share of commuters who use public transit and a higher share of households in poverty are both associated with a larger number of pedestrians struck by vehicles in predominantly white neighborhoods, even after controlling for home neighborhood racial characteristics, suggesting that they are travelling further to work.

We also conduct a multi-level model (not shown) that exploits individual-level victim age, victim gender, and crash location speed limit, along with the same neighborhood-level covariates presented in Table 6. The results of this model, in terms of significance and direction of the effect of home neighborhood race on crash likelihood, align with what we find previously and in Table 6.

Discussion

Our findings suggest an additional explanation for the disparities in injury by neighborhood socio-economic and racial and ethnic composition, an important dimension of health inequity. Beyond greater exposure to traffic crash risk on the streets near their homes, residents bring back traffic injuries from far-off neighborhoods. In generating a comprehensive view of Boston's experience, we have identified the magnitude of racially inequitable exposure to mobility risk. Annually, a member of roughly one in 360 households residing in the quintile of neighborhoods where most residents are people of color (97% on average) will experience an injury while walking or cycling, while in the quintile of neighborhoods that are mainly white (88% white on average), about one in 720 households are injured.

Injury and race research

Two documented determinants of crash risk are the built environment in which crashes occur and patterns of racial discrimination by drivers. Our analysis explores the possibility of a third factor, built around understanding the relationships between neighborhoods where pedestrians and cyclists are struck and their home neighborhoods by leveraging unique EMS records to link neighborhoods where people live to where people travel.

We find that pedestrians and cyclists who reside in neighborhoods where a majority of residents are people of color are struck by vehicles with greater frequency than those who live in neighborhoods where a majority of residents are white. This pattern aligns with previous findings on the location of traffic crashes. Part of the explanation may be related to the uneven distribution of safe street infrastructure. Yet, we also find that while residents of neighborhoods where the vast majority of residents are people of color account for about nine in ten of the victims who are struck in those

Table 6. Characteristics of victim's home neighborhood that predict crash frequency, by crash location.

	Dependent: Count residents in pedestrian crashes per capita, by type of location they crash				Dependent: Count residents in Bike crashes per capita, by type of location they crash			
Home neighborhood characteristics	All	White	Far	Far & white	All	White	Far	Far & white
Intercept	1.161 ***	0.997 ***	0.819 *	0.304 2.069	***	1.451 ***	1.116 ***	0.798 ***
	(0.593)	(0.291)	(0.337)	(0.174) (0.377)		(0.219)	(0.258)	(0.159)
% Black pop.	0.052 ***	−0.009 **	0.027 ***	0.002 0.010	**	−0.007***	0.005	−0.002
	(0.006)	(0.003)	(0.003)	(0.002) (0.004)		(0.002)	(0.002)	(0.002)
% Hispanic pop.	0.037 ***	−0.012 **	0.016 ***	0.002 0.001		−0.012***	−0.003	−0.006 **
	(0.008)	(0.004)	(0.005)	(0.002) (0.005)		(0.003)	(0.003)	(0.002)
% Asian pop.	0.020	−0.003	0.009	0.004 00000		−0.006	0.003	0.001
	(0.011)	(0.005)	(0.006)	(0.003) (0.007)		(0.004)	(0.005)	(0.003)
% Commuters - transit	0.004	0.011 *	−0.007	0.002 0.004		0.007	0.006	0.004
	(0.01)	(0.005)	(0.005)	(0.003) (0.006)		(0.004)	(0.004)	(0.003)
% Commuters - walk	0.003	0.003	−0.004	−0.001 −0.016	**	−0.009 **	−0.012 **	−0.008 ***
	(0.008)	(0.004)	(0.005)	(0.002) (0.005)		(0.003)	(0.004)	(0.002)
% Commuters - bike	0.049	0.042 *	0.010	0.010 0.117	***	0.057 ***	0.088 ***	0.044 ***
	(0.037)	(0.018)	(0.021)	(0.011) (0.024)		(0.014)	(0.016)	(0.01)
% Commuters − 5am-7am	−0.014	0.005	−0.008	0.001 −0.029	***	−0.015***	−0.013 *	−0.008 **
	(0.012)	(0.006)	(0.007)	(0.004) (0.008)		(0.005)	(0.005)	(0.003)
% Commuters − 4pm-12pm	−0.025	−0.009	0.005	00000 −0.031	*	−0.022 *	−0.005	−0.009
	(0.023)	(0.011)	(0.013)	(0.007) (0.015)		(0.009)	(0.01)	(0.006)
% Over-60 pop.	−0.005	−0.003	−0.001	00000 −0.003		−0.001	00000	00000
	(0.008)	(0.004)	(0.005)	(0.002) (0.005)		(0.003)	(0.004)	(0.002)
% Households in poverty	0.014	0.009 *	0.004	00000 0.007		0.003	−0.002	00000
	(0.009)	(0.004)	(0.005)	(0.003) (0.006)		(0.003)	(0.004)	(0.002)
Observations:	550	550	550	550 550		550	550	550
R2:	0.23	0.07	0.19	0.00 0.09		0.17	0.09	0.11

The leftmost panel reports the models for pedestrian crashes and the rightmost for cyclist crashes. We run a least squares regression on neighborhood level data, $Y = \mathbf{X}\beta + \epsilon^*$. We weight the model by population, where each an observation with population has a relatively lower weight since it contains less reliable information than an observation with large population. ***$p < 0.001$, **$p < 0.01$, *< 0.05.

Sources: Victim characteristics sourced from Boston EMS data. Neighborhood average characteristics sourced from American Community Survey, 2016–20 data.

neighborhoods, they *also* account for five in ten of the victims struck in predominantly white neighborhoods. This disparity may be partially a result of those residents being more likely to travel longer trips to get to work and other destinations, as illustrated by a higher share of residents with commute times of 45 min or longer. The results suggest that addressing mobility risk requires a holistic view of peoples' exposure that extends beyond where they sleep.

Access to adequate data poses a challenge to the ability to broadly identify the mechanisms connecting negative health outcomes in particular places to risks those residents face elsewhere. Much of the recent quantitative literature on risks to pedestrians and cyclists has examined the neighborhoods where crashes took place, as that is where it is possible to most easily associate demographic data with records of incident locations. Moving from an understanding of risk that ties *where people are injured* to one that also links risk to *where people live* requires exploiting data that cover individuals' full days, as we seek to do here using EMS data. The quantitative findings here suggest a need for qualitative accounts that spell out the causes and consequences of mobility risk. What mechanisms connect people of color and individuals with low incomes to the disproportionate exposure identified here? What burdens do those injured as pedestrians and cyclists shoulder? What factors are associated with the car drivers in these crashes (e.g. Mulford 1964)?

Policy implications

After World War II in the United States, federal funding flowed toward highway construction and subsequently highway safety programs; as cities sprawled into suburbs, local governments responded to the growing incidence of car-on-car crashes by creating ambulance systems. Over the past few decades, some policymakers and advocates have also elevated the goal of improving local street safety. The share of counties having invested in 'complete street' infrastructure to improve walking and biking safety grew 60% points between 1998 and 2014 (Mooney *et al.* 2018). Overall, these place-based changes to the built environment reduce fatalities (Porter *et al.* 2018, Richmond *et al.* 2014, Schneider *et al.* 2017; see, MacLeod *et al.* 2018 for a more cautious take). Underpinning these trends is a detailed literature on which interventions work best (e.g. Bella and Silvestri 2015, Kang 2019).

Traffic policy research is an expansive field, with a major focus on public responses to place-based risk stemming mainly from inadequately designed streets, but often forgoes solutions to neighborhood-level disparities that require crash data disaggregated by patients' residency details, which an invigorated research agenda on the sociology of injury could help to correct. Moreover, the salience of traffic crash risk for gig economy workers has now made even clearer the need to address risk not only based on where people are struck but, as a broader starting point, based on their daily risk profiles. Gig-economy couriers making deliveries may see their occupational and mobility risks fused or potentiated; they may stand to benefit from interventions like vest and helmet giveaways in the face of high crash rates (Christie and Ward 2019, Ahuja *et al.* 2021).

Annually, the United States experiences hundreds of thousands of traffic crashes whose victims require admission to emergency departments. Several steps could be taken to reduce this number, addressing our findings that, first, there are 2.7 times as many pedestrians struck in the least white compared to the whitest neighborhoods, and second, 4.1 times as many pedestrians are struck who reside in the least white neighborhoods compared to those from the whitest neighborhoods. The findings here identify the disproportionate mobility risk faced by communities of color, that, in this case, is roughly four times greater than the risk faced by white communities. Compared to existing studies, this research suggests that in total, residents of the least white neighborhoods are thus exposed to crashes at 1.5 times the rate that would be expected if one had just calculated exposure based on the demographics of where crashes take place. A substantial portion of this increased mobility risk is faced by residents of communities of color when they are traveling to predominantly white neighborhoods. This may be a consequence of the fact that employment in Boston is disproportionately located in neighborhoods whose residents are largely white and the fact that people in neighborhoods that are predominately inhabited by people of color have longer travel times to jobs.

First, street-design interventions that target the biggest crash hotspots, often in neighborhoods where the majority of residents are people of color, remain key. The City of Boston, for instance, has deployed a data-driven planning process for over a decade that uses EMS data to help orient street-design work toward consequential hotspots and has led to drops in bike and pedestrian incidents. For other cities, operational data from EMS responses to injuries might similarly help target work like this (Brennan 2024a). Pedestrians and bikers can benefit from different street design interventions targeting speed, visibility, distraction, compliance with traffic ordinances, and other factors that contribute to crashes. Second, targeting second-order crash hotspots that contribute to these disparities – hotspots that are often in largely white neighborhoods – would be beneficial; future research could help identify these. Third, beyond those built interventions, increased public health messaging in the specific home-neighborhoods where residents face the greatest risks could be beneficial as well. Fourth,

beyond place-based interventions, outreach on the basis of exposure, determined from sources like cell phone location data could precisely target at-risk individuals, such as couriers. Beyond crash volume and disparity, factors such as crash conditions (e.g., turn lane, rain, nighttime) and effectiveness of mitigation strategies, all of which may vary by neighborhood and patient segments, should come together to determine where cities steer interventions.

The most effective crash-prevention policies, however, are likely antipoverty ones: ready and flexible access to transport, daycare and afterschool care, primary health care, and housing, among other platforms of stability and opportunity, that when taken together would enable non-white residents and others disproportionately exposed to mobility risk to more safely navigate roads.

Conclusion

Traffic crashes are more commonplace in predominantly Black and Latino neighborhoods in two distinct ways—as places where pedestrians and cyclists are struck by vehicles, which aligns with previous planning and public health research, but also as communities whose residents are disproportionately exposed to traffic injury, even in other neighborhoods. People who live in predominantly non-white neighborhoods experience pedestrian and cyclist crashes at higher rates both in their own communities and in other areas of the city. For residents of Black and Latino neighborhoods, pedestrian exposure to crashes is a more frequent and consequential phenomenon that contributes to health inequality. Researchers utilizing EMS data can help cities better understand the impact of these crashes on their population. More research is needed to identify the underlying mechanisms of exposure to mobility risk. Policy action must be calibrated toward places with high crash rates, combined with distinct interventions that deliver relief to communities that bear the physical brunt of crashes.

Notes

1. Available at https://data.boston.gov/group/geospatial. Accessed on 1 May 2021. We used the longitude and latitude of where the ambulance stopped at the scene of each crash. While this is not necessarily the exact location where the crash occurred, ambulance drivers attempt to stop as close as possible – usually parking within 10 meters of the site – only stopping short because of street layouts, traffic flow concerns, and safety precautions. We catalogue street features that fall within about 100 feet (30 meters) of the probable crash site.
2. The scale of block groups – defined by the US Census Bureau – may be interpreted as neighborhoods and so are often used in similar investigations (e.g. Desmond 2012)
3. Available at https://www.census.gov/programs-surveys/acs. Accessed on 1 May 2021.
4. Available at https://lehd.ces.census.gov. Accessed on 1 May 2021.
5. These characteristics are typically correlated among individuals within block groups, making these quantities a helpful, albeit summarized, measure of the people who live in a place because of segregation of people by race and class across metropolitan areas.
6. 2016–20 U.S. Census American Community Survey data show that 44% of white Bostonians walked or took transit to work, compared to 45.7% Black and Hispanic Bostonians (only 41.7% of Black residents did so, but 50.5% of Hispanics did).
7. We work with quartiles instead of quintiles here because with the more granular quintile partition, in a few cases the median count of victims in Q1 was zero, making the ratio of Q4 relative to Q1 undefined; this made the table less intuitive to interpret. The results are qualitatively similar if we use quartiles or quintiles.
8. Among the candidate variables from Table 5 for the regression, we omit share residents with a BA or higher and share residents under 18 years old because they are highly correlated with percent residents Black, and we omit the percentage of residents with no access to a car because it is closely correlated with percentage of walking commuter residents and percentage of households in poverty. Whether or not we omit these variables, our results in Table 6 in terms of significance and direction of the effect of home neighborhood race on crash frequency is similar.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A

Table A1. Percentages of incidents by quintile for victim's home neighborhood race before and during the pandemic.

	All crashes		Pedestrian crashes		Bike Crashes	
Neighborhood Quintile	2016–2019	2020–2021	2016–2019	2020–2021	2016–2019	2020–2021
Least white	25.7	23.6	28.5	28.7	20.2	15.6
	25.4	27.9	27.5	29.0	21.1	26.2
	19.8	18.3	18.1	17.1	23.3	20.2
	17.4	19.2	15.2	15.6	21.8	24.8
Most white	11.7	11.1	10.7	9.6	13.5	13.3

The percentage of citywide crashes by before and during the pandemic.
Sources: Victim counts sourced from Boston EMS data. Neighborhood quintile characteristics sourced from American Community Survey, 2016–20 data.

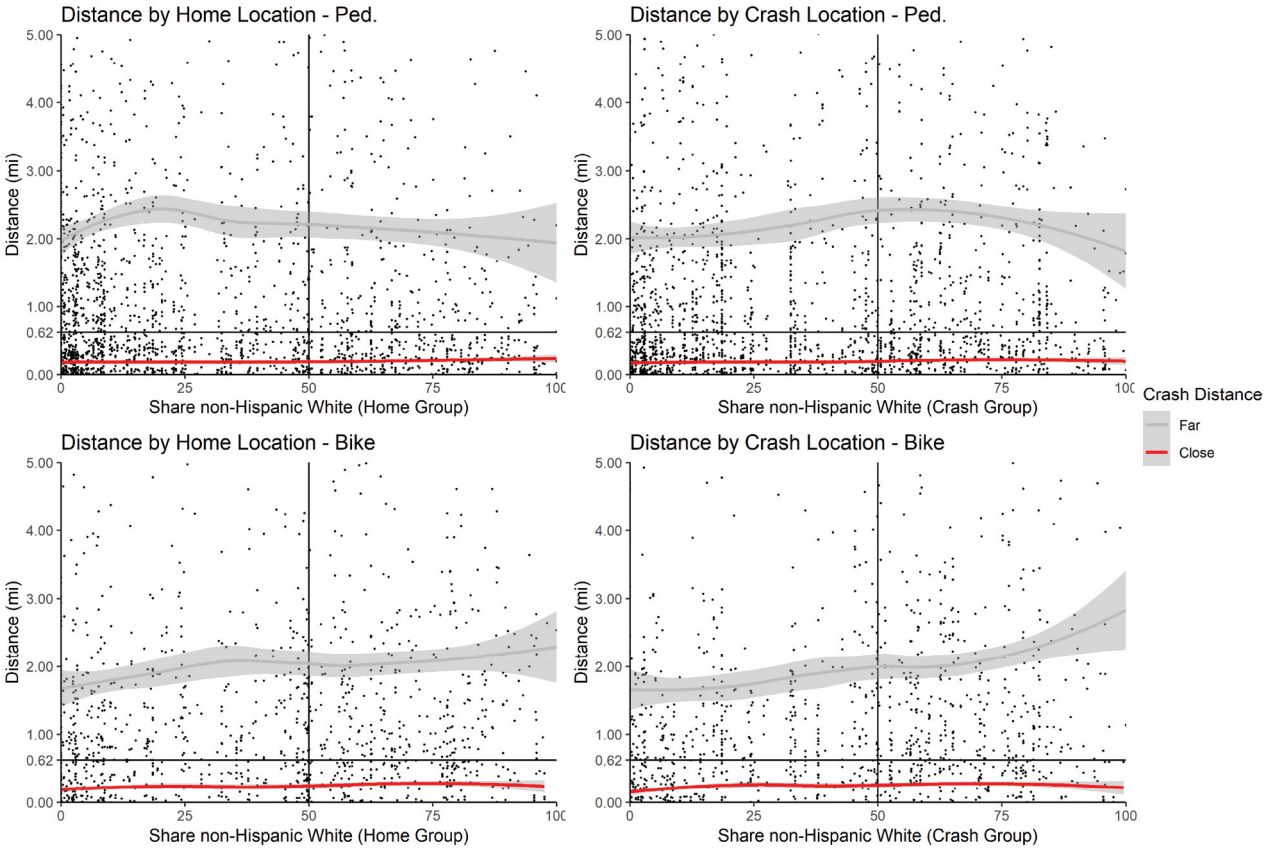

Figure A1. Crash distance trends for close and far-off crashes by home and crash block group racial composition. Horizontal line at 0.62 miles separates close from far crashes. Vertical line at 49.8% separates majority non-Hispanic white block groups from the majority of non-Hispanic white block groups. Red line is non-parametric regression for close crashes. Gray line is non-parametric regression for far crashes. *Sources*: Victim counts sourced from Boston EMS data. Neighborhood quintile characteristics sourced from the American Community Survey, 2016–20 data.

Table A2. Comparison of top and bottom quartile of various characteristics of crash neighborhoods, by location and racial or ethnic composition of home neighborhood.

	Quartiles		Pedestrian crashes, by home location								Bike crashes, by home location							
	Median of block groups in quartile		Ratio of median victims counts of block groups in Q4 relative to Q1								Ratio of median victims counts of block groups in Q4 relative to Q1							
Home neighborhood characteristics	Bottom quartile (Q1)	Top quartile (Q4)	All		Home in white neighborhood (>median)		In far neighborhood (>0.6 mi.)		In white & far-off neighborhood		All			Home in white neighborhood (>median)	In far neighborhood (>0.6 mi.)		In white & far-off neighborhood	
Pop. (in 1000s)	0.6	2.1	0.3		0.2		0.2		0.1		0.3		0.2		0.3		0.2	
Jobs (in 100s)	0.2	45.4	1.7	*	9.4	***	2.5	***	20.6	***	2.9	***	18.7	***	3.6	***	18.8	***
% White pop.	4.8	85.6	0.3	***	Inf	***	0.3	***	Inf	***	0.7	*	Inf		0.8		Inf	***
% Black pop.	0.4	63.4	1.4	**	0	***	1.2	**	0	***	1.2	**	0	***	0.8		0	***
% Hispanic pop.	2.7	44.6	0.7		0.1	***	0.4		0.1	***	0.8		0.1	***	0.6		0.1	***
% Asian pop.	0	26.3	0.4	**	0.4	**	0.3		0.2	*	0.7		0.7	**	0.8		0.8	**
% Commuters – 5am-7am	6.8	36.2	0.7		0.5	***	0.6		0.6		0.5	*	0.3	***	0.4	***	0.2	***
% Commuters – 4pm-12pm	0.2	13.9	0.6		0.2	*	0.4		0.1		0.8		0.3	*	0.8		0.3	*
% Households no car access	15.8	123.5	2.1	***	1.1		1.8	**	1		2.1	*	1.1		2.1	*	1.1	
% Commuting by transit	15.4	53.9	0.8		0.2	**	0.7		0.1	*	0.9		0.2	**	0.9		0.2	**
% Commuting by walking	0.1	41.6	0.7		0.9	***	0.7		0.7	***	0.9		0.9	***	1	*	1	***
% Commuting by biking	0	6.8	0.6	*	1.8	***	0.4	*	1.3	*	0.8		1.3	**	0.8		1	**
% Commuting by car	18.9	71.7	0.5	*	0.5		0.4	**	0.3	*	0.4	***	0.3	***	0.3	***	0.1	***
% Under-18 pop.	4.4	45.2	1.1		0.2	***	0.9		0.1	***	0.9		0.1	***	0.7		0.1	***
% Over-60 pop.	12.2	51.4	0.9		0.4	***	0.8		0.4		0.9		0.3	***	0.9		0.2	***
% Pop. with BA or higher	14.9	83.9	0.4	***	Inf	***	0.5	**	Inf	***	0.9		68.6	***	1.1		46.1	***
% Households in poverty	3.2	43	1	**	0.2	*	0.9	**	0.1		1.1		0.3	***	1.2		0.4	***
Speed limit	19	27.9	2.1	***	4	***	2.6	**	5.2	***	2	**	2.6	***	2.9	***	3.8	***
Any bikelane	0.2	1	1.5		2.6		1.9		4		1.6		2		2.2		1.9	
Distance traveled – ped.	0.1	2.2	2.9	***	4	*	33.1	***	35.2	***	-		-		-		-	
Distance traveled – bike	0.2	2.7	-		-		-		-		2.7	***	4.2	**	20.5	***	21.9	***

The leftmost panel reports the average among the block groups in the bottom quartile (Q1) and in the top quartile (Q4) for that characteristic. The second and third panels report the ratio of the average crash count per capita for Q4 to the average crash count per capita for Q1. The significance noted is the outcome of a Wilcox Test, which compares the distribution of crash counts for block groups in Q1 to the distribution of crash counts in Q4. The null hypothesis is there is no difference between the distributions. ***$p < 0.001$, **$p < 0.01$, * < 0.05.

Sources: Victim characteristics sourced from Boston EMS data. Neighborhood average characteristics sourced from American Community Survey, 2016–20 data and U.S. Census Longitudinal Employment-Household Dynamics 2019 data.